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PERCEIVED VELOCITY AND ALTITUDE JUDGMENTS DURING ROTARY WING AIRCRAFT FLIGHT

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September 1975

Final Report

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U. S. ARMY AEROMEDICAL RESEARCH LABORATORY

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Eight Army rotary wing aviators made judgments concerning the ground speed and altitude of a UH-1 helicopter. Combinations of three ground speeds and four altitudes were used across four visual conditions including daylight and simulated night environments. In general, the results indicate: (1) Absolute error in ground speed estimations increased as altitude increased. (2) At ground speeds above 50 knots there was a tendency to underestimate ground speeds and below 50 knots ground speed estimates were dependent upon visual conditions.

(3) Absolute error in altitude judgment increases with aircraft altitude. (4) At low altitudes the trend is toward underestimation and as altitude and airspeed increase the tendency is to overestimate altitude. These and other results are discussed as well as their possible implications for conduct of safe flight.

SUMMARY

Eight Army rotary wing aviators made judgments concerning the ground speed and altitude of a UH-1 helicopter. Combinations of three ground speeds and four altitudes were used across four visual conditions including daylight and simulated night environments. In general, the results indicate: (1) Absolute error in ground speed estimations increased as altitude increased. (2) At ground speeds above 50 knots there was a tendency to underestimate ground speeds, and below 50 knots ground speed estimates were dependent upon visual conditions. (3) Absolute error in altitude judgment increases with aircraft altitude. (4) At low altitudes the trend is toward underestimation and as altitude and airspeed increase the tendency is to overestimate altitude. These and other results are discussed as well as their possible implications for conduct of safe flight.

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INTRODUCTION

During the operation of helicopters, aviators often change altitude and airspeed as a function of terrain features and operational situation constraints. Accurate information concerning aircraft altitude and velocity, therefore, become important parameters for safe flight. This is particularly true in view of the US Army's terrain flight tactics which entail maneuvering the helicopter in close proximity to the ground and obstacles.

Successful terrain flight, especially nap-of-the-earth (NOE), requires rapid perceptual judgments and rapid control responses.[9] The pilot must direct most of his attention outside the helicopter leaving little time to observe cockpit instruments. Missions using the soon-to-be-deployed night vision goggles also require the aviator to focus his attention outside the cockpit. These flight situations, more than ever before, require the aviator to rely heavily on non-instrumentation cues as a basis for making aircraft altitude and velocity judgments.

Velocity judgment research, for the most part, has investigated the ability of subjects to predict the future location of a moving object under laboratory conditions. The moving object appears to the subject for a controlled period of time (display distance) and is then obscured from his view. The subject's task is to estimate the time it will take the object to move from the point of obscurity to a predetermined position (concealment distance.) The object normally consists of a moving bar or sequenced light patterns.

The general conclusions derived from these laboratory studies indicate:

(1) Time estimation accuracy improves with increased object velocity.[5,10]

(2) There is a tendency to overestimate time at low object velocities and underestimate at higher velocities.[5,10]

(3) The magnitude of absolute error involved in time estimation increases with concealment distance.[5,13]

(4) The percent of absolute error of time estimation decreases with concealment distance.[13]

(5) Subjects tend to underestimate the velocity of targets displayed for a short distance and overestimate those with increased display distances.[13]

Galanter[6] investigated time-to-touchdown judgments both in the laboratory and field studies. In the laboratory, subjects viewing motion pictures taken from fixed wing aircraft, during shallow and steep landing approaches, closed their eyes on cue and estimated the time it would take the aircraft to touchdown at a predetermined point on the landing field. The approaches were made at a relatively constant ground speed. The same general procedure was maintained for field studies with the subject viewing actual aircraft landing approaches. He reported that in both laboratory and field studies time-to-touchdown judgments were linear with respect to actual time and that there was a tendency to underestimate the time-to-touchdown. These data, of course, are not necessarily generalizable to rotary wing aircraft because rotary wing aircraft do not execute final approaches at fixed velocities as do fixed wing aircraft, but rather reduce airspeed during this maneuver such that a near zero velocity is achieved at touchdown or at a hover.

With regard to range judgments, a substantial amount of research has been conducted concerning the ability of ground observers to detect and estimate the range of moving aircraft. Baldwin,[3] reporting on a series of studies involving jet aircraft, propeller driven aircraft and helicopters, concluded that for distances greater than 3,000 meters (9,800 feet) range distance was overestimated (aircraft judged to be more distant); and for distance less than 1400 meters (4,700 feet) the tendency was to underestimate (aircraft judged to be nearer). On the other hand, the Applied Psychology Corporation investigation,[2] using a Convair C-131 and Twin-Beech C-45 as targets, found that ground observers tended to overestimate the distance of close aircraft (approximately 2.5 to 4 miles) and underestimate distant aircraft (approximately 5 miles to 7.5 miles).

In a series of experiments concerning aircraft flying at varied elevations and distances with respect to a ground observer, Galanter[7] examined the effect angle of regard had on range estimates. Aircraft elevation (angle of regard) was varied from 0° (on or near the horizon) to 90° (directly above observer). The distance of the target varied from a few hundred feet to over five miles. The results of those experiments indicated subjects overestimated target distance when the moving object was on or close to the horizon, underestimated when the moving object was directly overhead, and somewhere in between these two positions the perceived distance was equal to the actual distance. The perceived distance function was reported to be a power function with an exponent of 1.25 near the horizon and 0.8 at a 90° angle of regard.

With regard to airborne observers making range judgments, Galanter[7] in another experiment asked subjects to estimate distance to a target on the ground from an aircraft flying at an average altitude of 350 ft. above the ground. The majority of the distance estimates were made with the targets one to four miles away from the aircraft approximating an angle of regard equivalent to that of an aircraft flying near the horizon, when observed from the ground. The power function obtained from these data was 1.27 which closely resembles the power function obtained with ground observer distance estimates for low flying aircraft.

In a more recent study Galanter[6] examined distance-to-touchdown judgments using photographs taken from aircraft during shallow and steep landing approaches. The photographs depicted the view from an aircraft at distances from 10,000 ft. out to the point of touchdown at approach angles of 5^{o} to 10^{o}. The results indicate that for both experienced pilots and naive subjects the perceived distance-to-touchdown is a power function with an exponent of 1.24 and they tend to overestimate distance-to-touchdown. These results closely resemble those of low flying aircraft observed from the ground.

The above research is typical of that found in a review of current literature. Though related, it does not directly address the perceptual phenomena involved in air to ground velocity and altitude judgments during helicopter flight. Laboratory studies using inferred movement provided artificial cues for short periods of time. During actual helicopter flight, dynamic cues involving object shape and size, texture gradient, linear perspective and motion parallax are continuously available to aid the aviator in making distance and velocity judgments.

The research concerning the ability of ground observers to estimate the range of moving aircraft utilized aircraft as the object with the sky as a background. Helicopter to ground judgments on the other hand involve a higher density and variety of visual cues.

The time and distance to touchdown studies, involving fixed wing aircraft during landing approaches more closely resemble the conditions encountered while flying a helicopter. However, the constant ground speeds along a fixed angle of approach toward a predetermined point on the ground do not duplicate the changing conditions encountered during helicopter visual flight over varying terrain features. In addition, the research reviewed did not consider velocity and distance estimates while flying at night with the aid of night vision devices.

The objective of this study was to investigate the ability of rotary wing aviators to estimate aircraft altitudes and ground speed utilizing cues other than aircraft instruments. These phenomena were investigated

under both daylight and simulated night conditions. The effect of three independent variables--airspeed, altitude, and visual set--were considered.

METHOD

Subjects

Subjects were eight Army rotary wing aviators, age 24 to 38, with a mean age of 31. Total flight hours (rotary & fixed wing) varied from 700 to 2420. Rotary wing flight hours ranged from 120 to 2300. The mean flight hours of experience were 1727 total and 1277 rotary wing. Six of the pilots had prior experience flying at night (70-400 hours, mean = 170 hours.) Two aviators were familiar with night vision goggles, but only from laboratory demonstrations.

Apparatus

1. Aircraft

A JUH-1H helicopter instrumented with a radio ranging system which measures aircraft position over the ground was used. Position data were recorded in real time on an X, Y tracker/plotter located in the aircraft and calibrated to provide ground track information within ± 1 knot ground speed. A leading edge radar altimeter, AN/APN-198 (v) was used to measure the aircraft altitude above ground level (AGL). This device is accurate within ± 3%. A more detailed description of the instrumentation can be found in USAARL Report No. 72-11.

2. Night Simulators

A special pair of goggles were designed to simulate night illumination conditions during the day. These light weight goggles utilized Neutral Density Filters (N.D. 6.5) to reduce the illumination level at the subject's eye from normal daylight to the equivalent of approximately 25% of full moon illumination at night, i.e., 1/4 moon = 2.5×10^{-3} foot candles.[8] The subject's field of view (FOV) while wearing the night simulation goggles was 56° horizontal and 45° vertical.

3. Night Vision Goggles

Two sets of AN/PVS-5 night vision goggles were used during the experiment. These goggles, through the use of image intensification, allow the subject to see things at night that would normally be obscured. The first set of goggles provided the subjects a 40° circular FOV and the second a 60° FOV. Both were fitted with N.D. 6.5 filters similar to the night simulators above.

Design

A 3 x 4 x 4 random block factorial design[11] was applied with each subject being tested under all 48 possible combinations of the following independent variables.

a. Ground Speed (In Knots)

	DESIGN	ACTUAL		
		Min.	Average	Max.
Low	45	38	49	57
Medium	75	71	79	86
High	105	99	108	123

b. Altitudes (Feet Above Ground Level)

	DESIGN	ACTUAL		
		Min.	Average	Max.
1.	1500	1400	1470	1600
2.	500	400	500	600
3.	150	125	152	190
4.	75	60	72	95

c. Visual conditions

(1) Unaided eye under normal daylight illumination levels

(2) Unaided eye under simulated night illumination levels

(3) Aided eye, 60° FOV night vision goggles under simulated night illumination levels

(4) Aided eye, 40° FOV night vision goggles under simulated night illumination levels

Four orders of presentation of altitude/speed combinations were randomly selected, without replacement, such that neither the same altitude nor velocity levels were repeated from one trial to the next. (Appendix A) Visual sets were counterbalanced across subjects and

orders of presentation by use of a Latin square design.[1] (Appendix B) Each subject was randomly assigned to a 1-8 order as they arrived at the test location. In the event that a trial of any given subject was aborted due to equipment malfunction or environmental conditions, the next subject to enter was assigned the same subject number.

Procedure

The experiment was conducted in the field during daylight hours, between 0700 and 1600, over terrain consisting of pine forest with medium to heavy vegetation interlaced with open farm land. Terrain elevation varied from 50-200 feet above sea level. Clear skies were prevalent. Illumination levels were equivalent to normal daylight conditions (2×10^3- 1.19×10^4 foot candles). Illumination levels were measured on the ground prior to each flight using a photometer placed parallel to the surface of the earth. Night simulation was accomplished as previously mentioned through the utilization of neutral density filters. Each subject was allowed time for dark adaptation prior to conducting simulated night trials. In all cases the aircraft altimeter and airspeed indicators were masked to prevent the subject from obtaining information from them.

The aircraft was then flown to the first of the twelve velocity altitude combinations and stabilized by a research pilot. Each subject riding as an observer in the left seat was requested to alternatley look out the forward and left windscreens of the aircraft and to estimate the aircraft altitude above ground (in feet) and aircraft ground speed (in knots). After 15 seconds, on command, the subject reported his estimates to an on-board experimenter. The responses were recorded and the aircraft was then stabilized at a new altitude and velocity and the procedure repeated until estimates were obtained for each of the 12 altitude/velocity combinations. This scenario was repreated across each of the four visual sets.

RESULTS & DISCUSSION

Analyses of variance were performed on average constant error (ACE) and average absolute error (AAE) measures of altitude and ground speed estimates. These scores were derived by subtracting the measured ground speed and altitude for each subject trial from the subject's estimates of these parameters on each trial. For AAE the sign or the direction of error was not considered when computing the mean error while in the case of ACE the sign was considered. Only those factors producing an F ratios with a probability of .01 or less will be discussed.

The analysis of AAE for ground speed estimations revealed a significant altitude factor (See Table 1).

Table 1

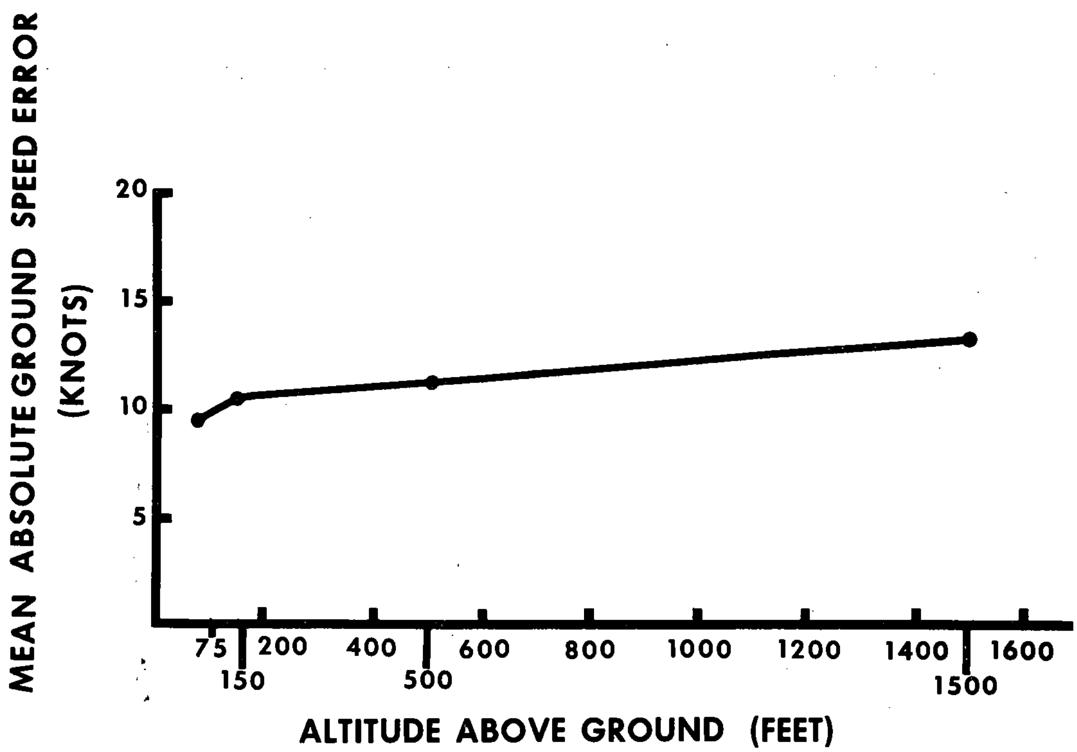
Analysis of Variance
AAE: Ground Speed Judgment

Source	df	MS	F
S (Subjects)	7	182.6	
A (Altitude)	3	287.5	6.52*
A x S	21	44.1	
B (Aircraft Ground Speed)	2	272.6	1.80
B x S	14	151.6	
C (Visual Condition)	3	29.0	.36
C x S	21	79.8	
AB	6	172.4	1.89
AB x S	42	91.5	
AC	9	43.1	.69
AC x S	63	63.0	
BC	6	36.0	.57
BC x S	42	63.3	
ABC	18	53.4	1.05
ABC x S	126	51.0	
Total	383		

*$p < .01$

A plot of the AAE ground speed estimates as a function of altitude is shown in Figure 1. It may be observed from this figure that as the aircraft altitude above the ground increases, there is a corresponding increase in the subject's AAE estimates of ground speed. The magnitude of error was on the order of 9 knots for the lowest altitude (75') increasing to 13 knots for the highest altitude (1500') An increase in error of estimated velocity as a function of altitude was not unexpected, since the visual cues which can be used to estimate ground speed, distance and velocity flow patterns would be adversely affected with increased altitude. A more unexpected finding was the relatively small differences in error over the range of altitudes used, although the altitude main effect was statistically significant. It was surprising that AAE was not significantly affected by ground speed or visual conditions. The laboratory studies reviewed indicated that the higher

ground speeds should have produced less AAE. Additionally, it was anticipated that FOV and resolution would have significantly affected this overall error measure.



GROUND SPEED ABSOLUTE ERROR AS A FUNCTION OF ALTITUDE

FIGURE 1

However, of more importance from an operational viewpoint is the ACE measure which yields information concerning the direction of the error and whether or not there is a tendency on the average to underestimate or overestimate ground speed. The analysis of variance for the ACE of velocity estimation can be seen in Table 2.

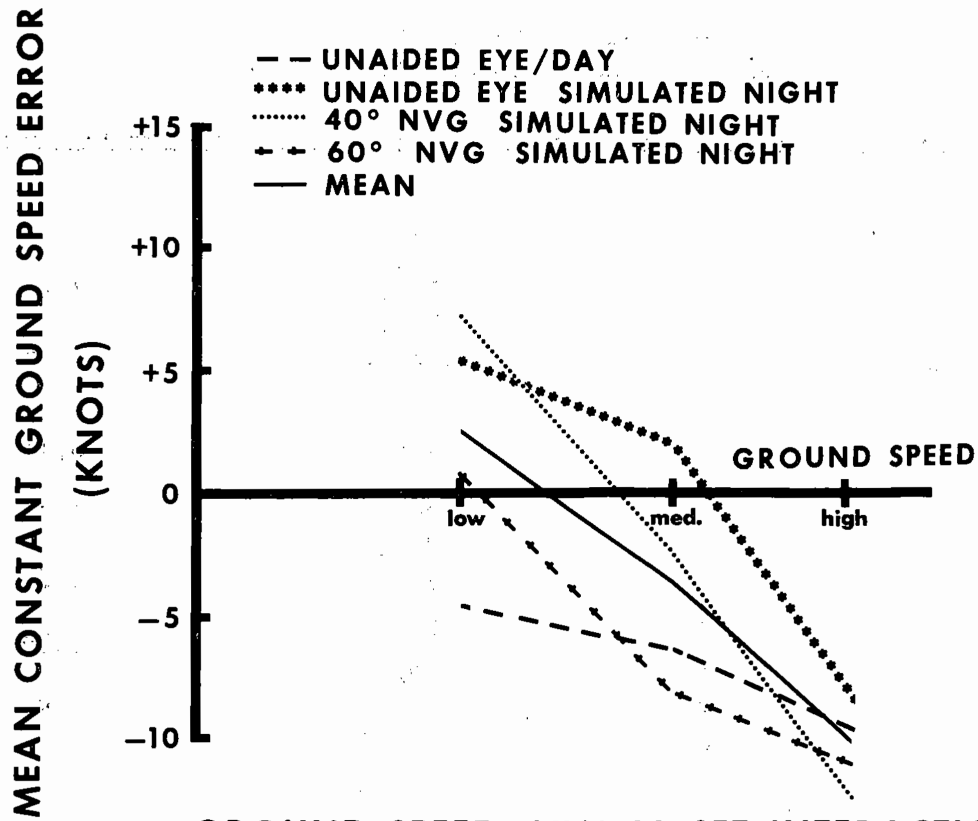
Table 2

Analysis of Variance
ACE: Ground Speed Judgments

Source	df	MS	F
S (Subjects)	7	745.5	
A (Altitude)	3	251.5	2.1
A x S	21	120.2	
B (Aircraft ground speed)	2	4722.2	11.0*
B x S	14	394.5	
C (Visual Conditions)	3	958.1	6.4*
C x S	21	150.5	
AB	6	201.3	1.0
AB x S	42	207.2	
AC	9	126.7	1.2
AC x S	63	103.5	
BC	6	308.6	3.5*
BC x S	42	88.2	
ABC	18	113.4	.9
ABC x S	126	127.1	
Total	383		

*$p<.01$

The analysis yielded significance for ground speed, visual conditions and the ground speed visual condition interaction. Inasmuch as the significant main effects were involved in the interaction, only the interaction will be discussed. This is necessary because the direction or magnitude of estimations was differentially affected by the parameters of aircraft ground speed and the visual conditions. The relationship between estimated ground speed, actual ground speed and visual conditions are shown in Figure 2.



GROUND SPEED—VISUAL SET INTERACTIONS

FIGURE 2

With the exception of the unaided eye daylight visual condition, ground speed was overestimated at the lowest aircraft speed. At higher aircraft speeds there was a tendency to underestimate ground speed under all visual conditions with a corresponding negative increase in error as aircraft speed increases. The disparity between visual sets with respect to average constant error is greatest at low speeds decreasing to a minimum at higher speeds. Since there was no interaction found with altitude, it can be assumed that the general direction of estimation was not significantly affected by this factor.

These findings can be viewed as critical in light of current mission requirements, particularly if obstacle avoidance is involved. For example, with the exception of the unaided eye daylight condition, there was overestimation at the lowest ground speed. This overestimation of ground speed could be construed to be conservative because one may tend to estimate arrival at a point prior to actually being there. This in turn may prompt the aviator to begin the avoidance maneuver early, therefore, providing an obstacle clearance greater than necessary. By the same token, the tendency to underestimate at higher velocity could provide the converse. If the aviator had to rely solely on noninstrument cues and was traveling at ground speeds of approximately 50 knots or higher when using the unaided eye during the day or 60° FOV night vision goggles at night, he may well estimate his time of arrival at a point or

obstacle to be greater than will actually be the case. This condition would also hold if flying with the unaided eye at night or with 40° FOV night vision goggles but at higher ground speeds. The aviator could experience difficulty in these situations by arriving at a point or obstacle sooner than expected. If avoidance maneuvers were necessary, the initiation of such maneuvers may be introduced too late to avoid collision.

However, there is some question with respect to linking these ground speed estimations to estimated time to reach obstacles. Recall that Galanter,[6] in both field and laboratory studies concerning fixed wing aircraft, reported a tendency to underestimate time to touchdown, i.e., pilots thought they were moving faster than was the case. In this study, with the day unaided eye all three levels of ground speed yielded negative ACE estimations, which in turn means the aviators judged their ground speed to be slower than it was. The disparity between these two results may be attributable to the difference in the respective flight profiles. In Galanter's study time-to-touchdown estimates were made with respect to a fixed point on the ground and with the aircraft in one of two approach attitudes. In the present study, ground speed estimates were made with the aircraft in level flight without a required reference on the ground. A difference in flight attitude would tend to alter the velocity vector field perceived by the subjects. The velocity field in turn has been linked to perception of vehicle speed.[12] It should also be pointed out that the laboratory studies reported trends for increased underestimation as velocity decreased while the opposite trend was found in this study. The difference in this case may be a function of the direction of movement. In the present study, the aircraft moved across the ground in a longitudinal direction. While in the laboratory studies the object moved along a lateral path perpendicular to the subject's line of sight.

The reason for the differential effect as a function of visual condition is not clearly understood, but could perhaps be related to the field of view and the reduction of peripheral cues. Studies concerning velocity estimates associated with ground vehicles have concluded that peripheral visual stimulation is a significant factor in obtaining accurate velocity judgments.[12]

It should also be noted that subjects in this study, when questioned about cues used to determine aircraft velocity, reported aircraft sound and vibration were utilized in addition to visual cues. It appears plausible that these nonvisual cues could play an increasingly important role as the FOV is reduced.

Altitude estimations were also acquired under the same conditions as were velocity estimations. ACE and AAE measures were derived from the altitude estimation data. Table 3 presents the analysis of variance for the AAE for altitude judgments.

Table 3

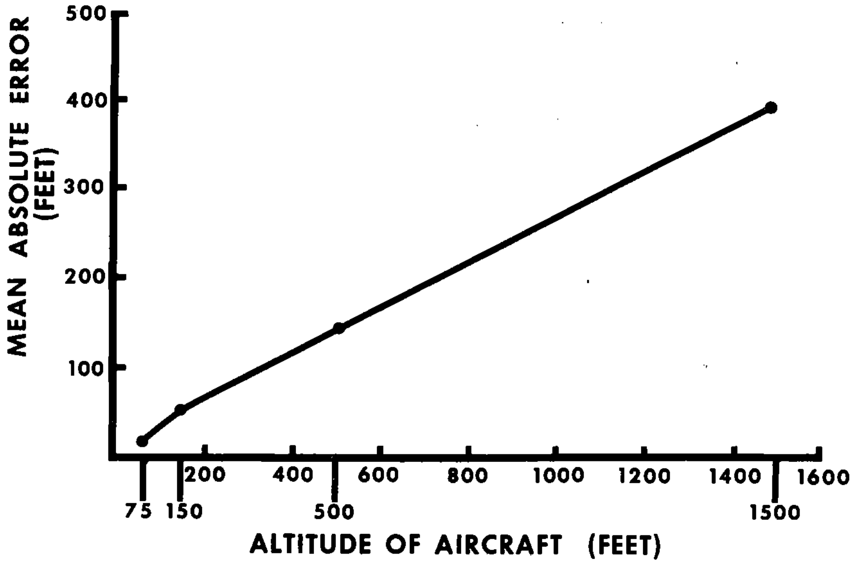
Analysis of Variance
AAE: Altitude Judgments

Source	df	MS	F
S (Subjects)	7	317355.0	
A (Altitude)	3	3506480.0	18.8*
A x S	21	186159.0	
B (Aircraft ground speed)	2	51747.0	1.3
B x S	14	39733.9	
C (Visual condition)	3	108286.7	1.9
C x S	21	57853.1	
AB	6	14511.0	.5
AB x S	42	28523.5	
AC	9	45017.3	1.3
AC x S	63	34733.6	
BC	6	2633.8	.1
BC x S	42	23793.3	
ABC	18	23390.6	.9
ABC x S	126	25800.1	
Total	383		

*p<.01

For this measure only the factor of altitude yielded significance. A plot of the means for this factor is shown in Figure 3.

The AAE in judging altitude increased as aircraft altitude increased. The magnitude of error was on the order of 25 feet at the lower altitude increasing to approximately 400 feet at the highest altitude. This relationship is similar to that found with respect to ground speed judgment. It is suspected that the reasons are similar, in that visual cues for estimating altitude would tend to be affected as altitude increased. Exactly what cues are utilized is not known, but in our opinion, may include apparent size, texture gradient and relative motion. Subjects reported that apparent size was frequently used to estimate altitude.



MEAN ABSOLUTE ERROR AS A FUNCTION OF ALTITUDE

FIGURE 3

The analysis of variance for the ACE measure can be seen in Table 4.

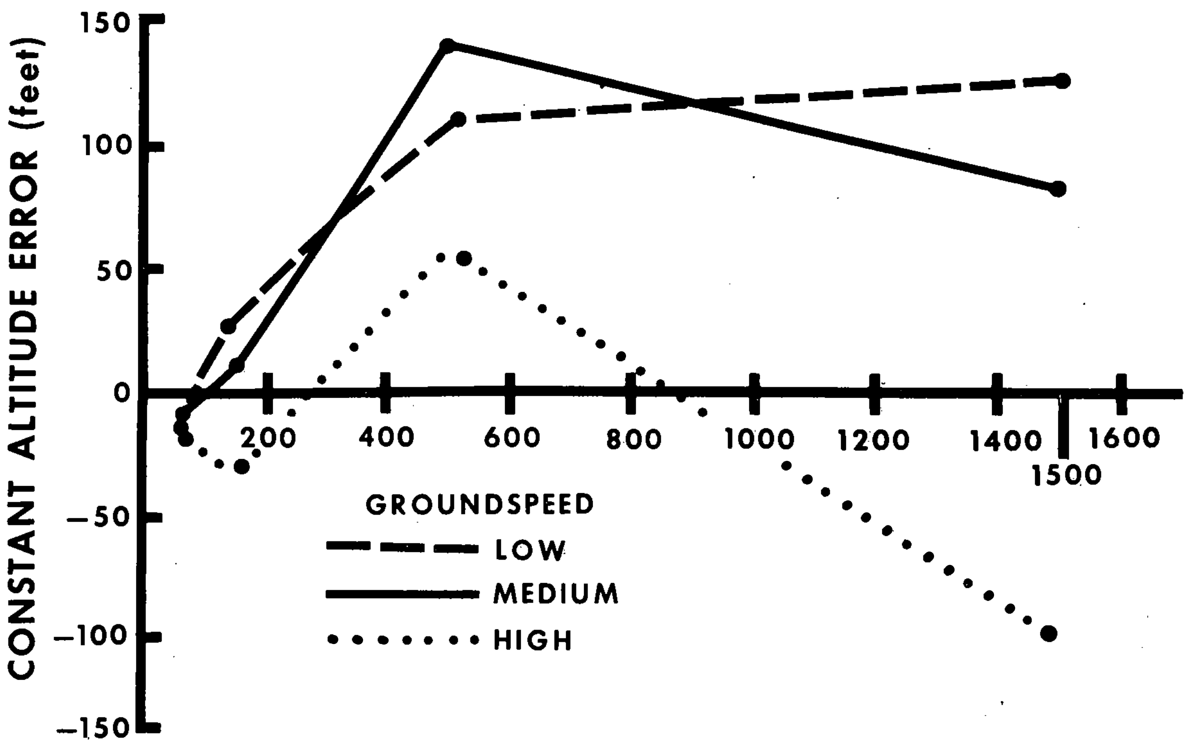
Table 4

Analysis of Variance
ACE: Altitude Judgment

Source	df	MS	F
S (Subjects)	7	567357.0	
A (Altitude)	3	265079.8	.45
A x S	21	592939.2	
B (Aircraft ground speed)	2	329431.3	8.6*
B x S	14	38203.1	
C (Visual condition)	3	18479.8	1.6
C x S	21	115788.7	
AB	6	104179.3	4.4*
AB x S	42	23468.6	
AC	9	136180.2	2.5
AC x S	63	55246.3	
BC	6	11134.1	.3
BC x S	42	34295.4	
ABC	18	31028.7	.8
ABC x S	126		
Total	383		

*p<.01

Aircraft ground speed and the ground speed/altitude interaction were significant factors. Again, since ground speed interacted with altitude, only the interaction will be discussed. Examination of the ground speed error curves at the given altitudes tested (Figure 4) shows a tendency for subjects to underestimate their altitude at the lowest altitude condition irrespective of the ground speed at which the aircraft was flown. This underestimation continued for the highest ground speed to the 150' altitude, but not for the other ground speeds. At 500', the highest ground speed was also associated with overestimation, but reverted back to underestimation at 1500'. Above the 75' altitude the lower ground speeds were associated with overestimating altitude. That is, they judged the aircraft to be higher than was actually the case.



ALTITUDE-GROUNDSPEED INTERACTIONS

FIGURE 4

From an operational point of view, underestimation at low altitudes has a variable impact. For example, when flying low level, aviators who estimate themselves to be lower than is the true state of affairs may tend to fly at a higher altitude than intended, thereby providing a safety margin with respect to terrain clearance. On the other hand, if the objective is to fly as low as possible, in view of a known threat which must be countered by the concealment provided by low level flight, the converse may be true. The aviator may fly higher than the required minimum clearance, thereby increasing aircraft exposure. When the mission contraints require NOE or contour flying profiles, the aircraft will at times be at an altitude that is lower than the uppermost point of the surrounding natural terrain or man-made objects. In this situation, a lower estimated altitude could lead to problems with respect to obstacle avoidance. If altitude is used as a yardstick (height reference) for determining the unknown height of an obstacle, a lower estimated altitude may lead to a judgment of a smaller relative distance to the top of the obstacle. If this were the case, the obstacle avoidance maneuver (aircraft ascent), may not be initiated soon enough to safely clear the obstacle. On the other hand, if the actual height of the obstacle is known and aircraft altitude is thought to be lower than it actually is, it could lead to the conclusion that the relative distance from the aircraft to the top of the obstacle is greater than it actually is. This in turn would lead to initiation of the aircraft ascent sooner than required, thereby breaking concealment earlier than necessary. The overall impact of altitude judgments during NOE, contour and low level flight appear to produce dichotomous results dependent on the specific mission and knowledge of the terrain.

In summary, it appears that the salient information gained from this study was:

1. Absolute error in ground speed estimates increase as altitude increases.

2. Above 50 knots ground speed, across all visual conditions, ground speeds are estimated to be lower than is actually the case.

3. Below 50 knots ground speeds are both over estimated and underestimated depending on visual conditions. Underestimations were predominant with the unaided eye during the day while night simulated conditions precipitate overestimation.

4. Absolute error in altitude judgment increases with aircraft altitude.

5. At low altitudes the aircraft is estimated to be lower than is actually the case.

6. As altitude and airspeed increase there is a tendency to overestimate altitude, but this effect is differentially affected by ground speed.

The data from this study indicated that trends do exist concerning the rotary wing aviator's ability to judge aircraft altitudes and ground speeds using noninstrumentation cues. They are, however, dependent on actual altitude, ground speed and visual conditions as well as altitude/airspeed interactions. The impact of these findings from the operational point of view are varied and must be considered in light of specific mission requirements.

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Appendix A

Presentation Order

1		2		3		4	
Alt	G/S	Alt	G/S	Alt	G/S	Alt	G/S
500	L	1500	M	150	M	75	L
150	H	75	M	1500	L	150	M
75	L	150	L	75	H	1500	L
150	M	500	H	500	M	75	H
1500	L	1500	M	1500	H	500	M
75	H	500	L	75	M	1500	H
500	M	150	H	150	L	75	M
1500	H	75	L	500	H	150	L
75	M	150	M	1500	M	500	H
150	L	1500	L	500	L	1500	M
500	H	75	H	150	H	500	L
1500	M	500	M	75	M	150	H

Appendix B

Subject, Presentation Order, Visual Set

	1	2	3	4	
S_1	A	C	B	D	S_5
S_2	B	A	D	C	S_6
S_3	C	D	A	B	S_7
S_4	D	B	C	A	S_8

A = Unaided eye/day

B = Unaided eye/night

C = 40° goggles/night

D = 60° goggles/night